Chapter 17
Non-symmetrical Force–Deflection Behavior of a NiTi Archwire in Orthodontic Leveling Treatment

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Abstract Orthodontics is a branch of dentistry that focuses on dealing with irregularities of teeth such as malocclusion. The orthodontic treatment helps in aligning and straightening teeth which aim to improve the aesthetic appearance and healthy masticatory function. This study was designed to investigate the bending deformation behavior of nickel-titanium (NiTi) archwires in non-symmetrical brackets mounting configuration in orthodontic leveling treatment. A three-bracket bending test was performed in a dry condition at room temperature, 25.5 °C, and testing temperature, 35.5 °C, in compliance with the ISO 15841—Dentistry: wires for use in orthodontics. The NiTi archwires used were 0.016-in. round and 0.016 × 0.022-in. rectangular. The brackets used were made of 0.022-in. stainless steel. For the non-symmetrical loading, the load position is offset by 0.25 mm incremental, up to 1.5 mm from the center. The archwire was deflected to a maximum of 4 mm. Force–deflection curves are plotted from the results of the bending test. The archwire recovered from the greater force magnitude during activation will release at a lower force magnitude at the start of the deactivation stage. An increase in temperature from 25.5 to 35.5 °C increases both activation and deactivation forces. The same behavior was also observed on the rectangular wire, except that the force level on activation and deactivation are higher due to differences. Offsetting the inter-bracket distance requires higher force for the wire deflection, which decreases the internal energy with the leveling treatment process.

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17.1 Introduction

Orthodontic treatment is also known as a method to improve the look and arrangement of teeth by straightening or moving the malpositioned teeth into the desired position. Generally, orthodontic treatment can be fractionated into three stages: the initial stage, the intermediate stage, and the finishing stage (Yoneyama and Miyazaki 2008). In each stage of treatment, the required properties of the wire are considerably different. During the earliest stages of orthodontic therapy, the NiTi archwire is favored above other metal orthodontic wires. One of the reasons is due to less time required to accomplish leveling and less discomfort that patients get with the use of NiTi archwires as indicated by Andreasen and Morrom (Kapila and Sachdeva 1989).

17.2 Literature

NiTi archwires have advantages over others metal orthodontic wires because of shape memory and superelastic properties. In orthodontic treatment, the engagement of archwires occurred in the bracket slots that are attached to the teeth for moving teeth to the desired position which can improve the appearance of the teeth. NiTi archwire is regarded as a good archwire because it can consistently supply enough force for tooth movement, reducing the risk of patient pain, periodontal ligament damage, and resorption undermining (Gurgel et al. 2001). This force should be low and delivered continuously over a suitable period (Nespoli et al. 2015). The goal is to keep a force on the teeth practically continually during treatment, from the very aberrant position for the rest to the almost perfect alignment at the end (Siegner and Ibe 2000).

Force delivery capabilities by the NiTi archwire in orthodontics treatment are the most favorable (Ahmad et al. 2019). Knowing a specific magnitude of force during activation and deactivation is necessary to provide the optimum and predictable treatment results (Youyi et al. 2000). The activation force and deactivation force are two forces that play important roles in orthodontic treatment. The activation force is the force that is required to bend the archwire during engaging it into the orthodontic bracket, while the deactivation force of the orthodontic archwire is formed when it tries to go back to its original formed shape which causes the tooth to move into the desired location. The deactivation force becomes the primary concern in orthodontic treatment.

This research deals to evaluate the force–deflection behavior encountered in nonsymmetrical bracket mounting configuration in orthodontic leveling treatment. This condition resembles the variation of tooth size between canine, central incisor, and lateral incisor. The effect of different wire geometry will also be evaluated. Finally, the force magnitude from the force–deflection curve is discussed to analyze the performance and behavior of NiTi archwire.

17.3 Methodology

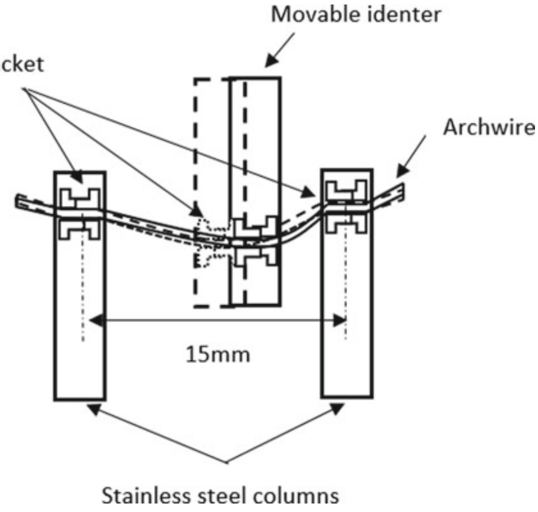
The experimental test performed in this study is the three-bracket bending test as shown in Fig. 17.1. The three-bracket bending represents the leveling treatment on the maxillary arch by aligning three brackets that correspond to the lateral incisor, canine, and first premolar. The three-bracket bending test is conducted by using a universal testing machine (Model 3367, Instron) with a 500 N load cell installed. The result from the bending test will be used to plot the force–deflection curve, thus reflecting the behavior exhibited by the archwire.

In the test, 0.022-in. stainless steel bracket sizes are used together with 0.016-in. round NiTi archwire and 0.016 × 0.022-in. rectangular NiTi archwire. The 20 mm NiTi archwire specimen was cut from the archwire's straight-end segment. A UTM crosshead speed of 1 mm/min deflected the archwires from 2.0 to 4.0 mm. The deflection range was chosen due to the range of possible occasions under clinical conditions.

The canine was represented by the central bracket, which was mounted on the adjustable indenter, and the lateral incisor and first premolar were represented by the adjacent brackets, which were installed on the fixed supports, as shown in Fig. 17.2. Using cyanoacrylate adhesives, the brackets were bonded to the mobile indenter and mounting base. In this wire-bracket design, no ligation tie was added. As a result, there is no friction caused by the ligation tie when it drives the archwire against the bracket slot's base. The tests were carried out at 25.5 °C ambient temperature and 35.5 °C oral temperature, with the test apparatus being put in a temperature-controlled chamber and the full test being carried out inside the chamber at the chamber's set temperature. Offsetting the movable indenters by 0.25 mm incrementally, up to 1.5 mm from the center, is used to investigate non-symmetrical force–deflection behavior.

Fig. 17.1 Experimental setup of three-bracket bending test

Fig. 17.2 Schematic of the unsymmetrical three-bracket bending setup



17.4 Result and Discussion

Force–deflection curves on round and rectangular archwires at two different temperatures, under symmetrical bending tests, are shown in Fig. 17.3. The activation cycle starts with a linear slope until 0.8 mm and 1.00 m deflection distance on the round and rectangular archwire, respectively. The plateau shown in the figure transformed into slope a trend and the activation force is high in comparison with the three-point bending which indicated that friction incorporates in this test due to bracket-wire contact. Increases in offset and deflection distance showed to increase in activation and decrease in deactivation force. This indicated that high offset and deflection distance causes more difficulty for the archwire to bend during installation and decreases the internal energy of the archwire during leveling treatment. The activation force is higher on rectangular archwires compared to round archwires following the bending stiffness.

17.4.1 Non-Symmetrical Three-Bracket Bending

Force–deflection curves of round and rectangular NiTi archwires at 4 mm deflection on non-symmetrical bending at room temperature, 25.5 °C, are shown in Fig. 17.4. The linear slope on the activation cycle is nearly identical with symmetrical bending test for offset distance below 0.75 mm and 1.25 mm on the round and rectangular archwire, respectively. However, above that offset distance, the linear slope on both archwires is shown to end at an early deflection distance. This is potentially due to increased offset distance, which the wire contact at the edge of the bracket to occur faster. This subsequently gives enough stress for the archwire to change its

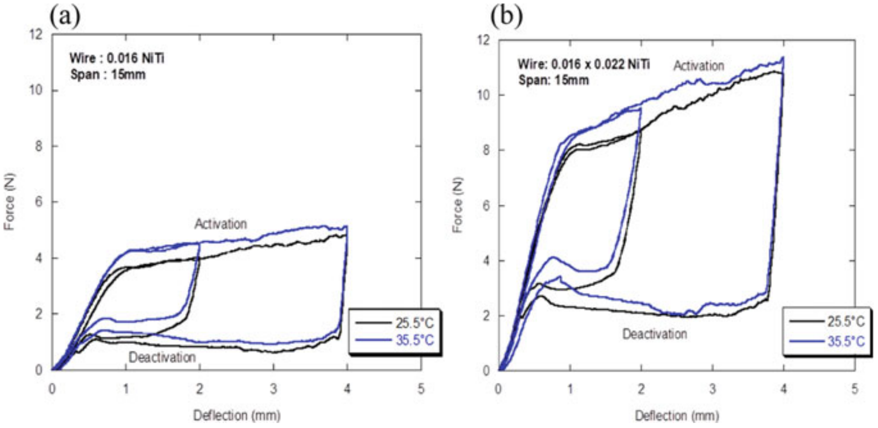


Fig. 17.3 Force–deflection curves on symmetrical bending registered at 2 and 4 mm deflection at two different temperatures on **a** 0.016 round NiTi and **b** 0.016 × 0.022 rectangular NiTi

crystalline structure from austenite to martensite at an earlier deflection distance. Moreover, increases in the offset distance also led to an increase in the activation force and a decrease in the deactivation force. The archwire exhibits the larger magnitude of activation force shown to release at the lower magnitude of deactivation force. Over the reduction of the deflection distance, the deactivation force increases back because of weakened binding intensity as more free play is introduced between the wire bracket. The start of stress-induced martensitic transformation (SIMT) was also shown to it at lower stress with the increase of offset distance above 0.75 mm and 1.25 mm on the round and rectangular wire, respectively.

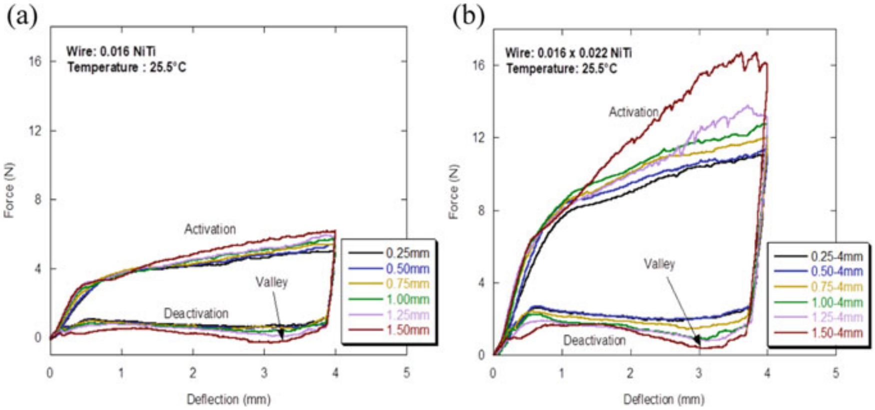


Fig. 17.4 Force–deflection curves on non-symmetrical bending at 25.5 °C on **a** 0.016 NiTi **b** 0.016 × 0.022 NiTi

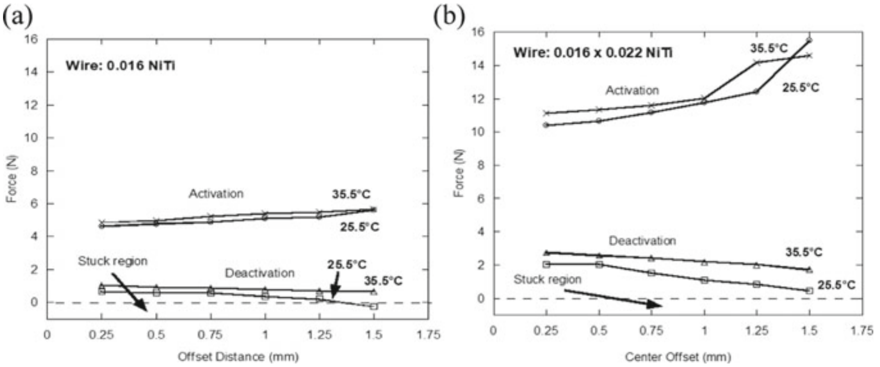


Fig. 17.5 Force magnitude of activation stage and deactivation stage at 3 mm deflection and two different temperatures over various offset distances; **a** 0.016 NiTi round archwire and **b** 0.016 × 0.022 NiTi rectangular archwire

Figure 17.5 summarizes the force magnitude acting between the round and rectangular NiTi wire at two different temperatures over various offset distances. The force magnitude increases when the offset distance decreases at the activation stage. The behavior that occurred behind this is due to the increment in binding friction coefficient with the increase of offset distance. Besides, offsetting the inter-bracket distance decreases the wire length between one side of the bracket edge and this delayed the force to a higher magnitude. However, upon the deactivation stage, the force magnitude decreases as the offset distance increases due to more spring back needed by the wire to overcome the binding friction (Ahmad et al. 2020a, b; Gurgel et al. 2001; Lombardo et al. 2012; Razali and Mahmud 2019; Proffit et al. 2012).

For the case of 1.50 mm offset distance on the round wire during the deactivation stage, the force magnitude entered the stuck region where force is below 0 N. This indicated that the spring-back was fully enrolled by the wire to overcome the binding friction. Therefore, additional force is required to overcome the stuck region. 0.016 NiTi round seems not suitable to be applied by the orthodontist to overcome this situation. This can be replaced by 0.016 × 0.022 NiTi rectangular wire as the force magnitude acting on this situation actions on the desirable force which is around 0. Overall, 0.016 × 0.022 NiTi rectangular wire force magnitude acting on overall is two times higher than for the 0.016 NiTi round wire.

17.4.2 Influence on Clinical Perspectives

"Light continuous force" is a favorable term used in orthodontic to encourage comfort to the patient during treatment. However, until now there is no research found that the ideal force (light) is being applied by the archwire with continuity (Proffit et al.

2012). This term somehow encourages many researchers to evaluate the force being acted by the wire in many cases encountered clinically.

In this present study, the results provide here give some insight to the orthodontist on how the tooth size discrepancies affect the force level during both the activation and deactivation stage. A combination of 0.016 × 0.022 archwire with 0.022-in. stainless steel bracket is not suitable to be used as most deactivation force is acting above 1.0 N which then provides ineffective tooth movement (Youyi et al. 2000). The usage of the rectangular wire at the end of the leveling treatment should be reconsidered in order to acquire access to the "light continuous force". In the trend of the archwire to exert a lower force during deactivation with the increase of offset distance, it becomes a necessity for the researcher to study the force system exhibited when introducing a loop into the archwire which might be the answer in facing smaller teeth size. Finally, warm water should be avoided in this scenario to decrease pain because the deactivation force is nearly 1.0 N at oral temperature. Because the NiTi archwire is temperature sensitive, consuming warm water causes the archwire to deliver at a higher force.

17.5 Conclusions

The bending deformation behavior of NiTi archwire under non-symmetrical three-bracket bending was evaluated in this study. The temperature difference and wire sizing toward alteration of force magnitude during both activation and deactivation have been done in a variety of offset distances. The main findings from this work include the following:

1. Due to the obvious friction between the wire and the brackets, the NiTi wires show a plateau transition into a slope.
2. By increasing the offset distance of the deflection load, the force required to bend the wire increased due to the difficulty to bend the wire at a shorter span.
3. By increasing the testing temperature, the force required to induce martensite phase transformation of the NiTi alloy in bending increased because the testing temperature is further higher than the austenite finish temperature.
4. The bigger cross-sectional area on 0.016 × 0.022 NiTi rectangular archwire compared to 0.016 NiTi round archwire resulted in higher activation and deactivation forces magnitude due to higher friction associated with more contact between bracket slots occurred.

References

Ahmad MN, Mahmud AS, Razali MF, Mokhtar N (2019) Force-deflection behaviour of NiTi archwires in a polytetrafluoroethylene (Teflon) bracket system. Mater Sci Eng Technol 50(3):289–294

Ahmad MN, Mahmud AS, Razali MF, Mokhtar N (2020a) Binding friction of NiTi archwires at different size and shape in 3-bracket bending configuration. Adv Struct Mat 131(2):25–32

Ahmad MN, Mahmud AS, Razali MF, Mokhtar N (2020b) Force-deflection behavior of NiTi archwire at different configurations of bracket system. Materwiss Werksttech 51:10

Gurgel JA, Kerr S, Powers JM, LeCrone V (2001) Force-deflection properties of superelastic nickel-titanium archwires. Am J Orthod Dentofacial Orthop: Official Publication of the American Association of Orthodontists, Its Constituent Societies, and the American Board of Orthodontics 120(4):378–382

Kapila S, Sachdeva R (1989) Mechanical properties and clinical applications of orthodontic wires. Am J Orthod Dentofacial Orthop 96(2):100–109

Lombardo L, Marafioti M, Stefanoni F, Mollica F, Siciliani G (2012) Load deflection characteristics and force level of nickel titanium initial archwires. Angle Orthod 82(3):507–521

Nespoli A, Villa E, Bergo L, Rizzacasa A, Passaretti F (2015) DSC and three-point bending test for the study of the thermo-mechanical history of NiTi and NiTi-based orthodontic archwires: the material point of view. J Therm Anal Calorim 120(2):1129–1138

Proffit WR, Fields HW, Sarver DM (2012) Contemporary orthodontics. Elsevier (Fifth), London

Razali MF, Mahmud AS (2019) Computational study on the effect of contact friction towards deactivation force of superelastic NiTi arch wire in a bracket system. Mater Res Express 6(8):85709. https://doi.org/10.1088/2053-1591/ab2255

Siegner D, Ibe D (2000) Clinical application of shape-memory alloys in orthodontics. In: Yahia L (ed) Shape memory implants. Springer, Berlin, pp 210–228

Yoneyama T, Miyazaki S (2008) Shape memory alloys for biomedical applications. In: Shape memory alloys for biomedical applications. Sawston, United Kingdom

Youyi C, Ming Z, Fengzhi Y (2000) Orthodontic application of NiTi shape-memory alloy in China. In: Yahia L (ed) Shape memory implants. Springer, Berlin, pp 229–235